# *Optimizing and Quantifying $CO_2$ Storage Capacity/Resource in Saline Formations and Hydrocarbon Reservoirs*

**U.S. DOE NETL Carbon Storage R&D Project Review Meeting**
**Pittsburgh, Pennsylvania**
**August 12–14, 2014**

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**Senior Research Manager**

Energy & Environmental Research Center (EERC)

# Presentation Outline

- Project overview
- Saline formations
  - Base case geocellular models complete (nine)
  - Simulations on base case models complete (nine)
  - Optimization cases ongoing
- Hydrocarbon reservoirs
  - Base case geocellular models complete
  - Simulation on oil reservoir fluvial base case complete (one)
  - Simulation on other oil reservoir base cases ongoing (11)
  - Simulation of base case gas reservoirs ongoing (12)

# Project Overview

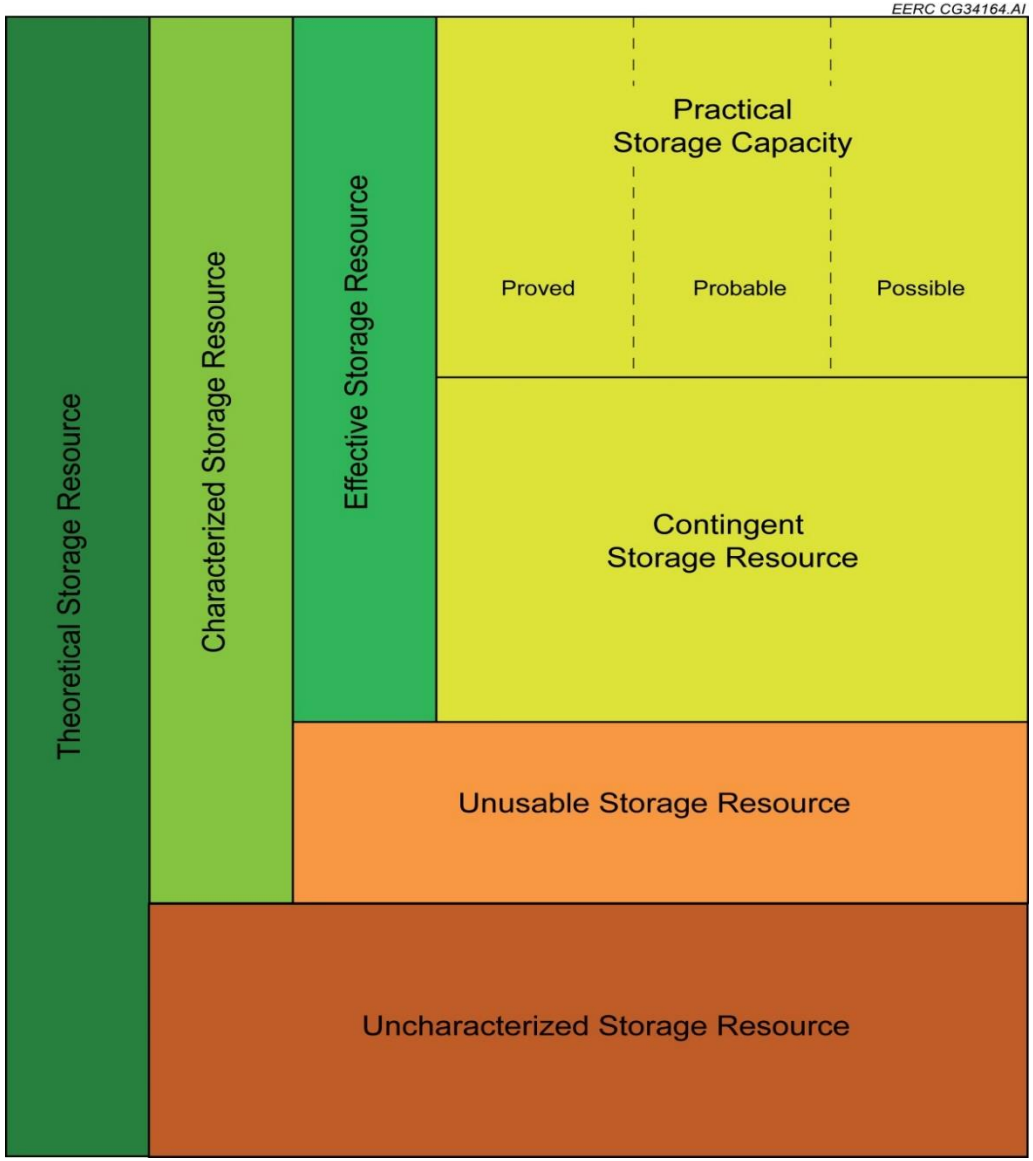
## Goal

- To refine current methods and terms used to estimate $CO_2$ storage resource in saline formations and hydrocarbon reservoirs.
- Two concurrent areas of investigation will be undertaken to accomplish project goals:

Optimizing and Quantifying $CO_2$ Storage Resource in **Saline Formations**

Optimizing and Quantifying $CO_2$ Storage Resource in **Hydrocarbon Reservoirs**

# $CO_2$ Storage Resource/Capacity

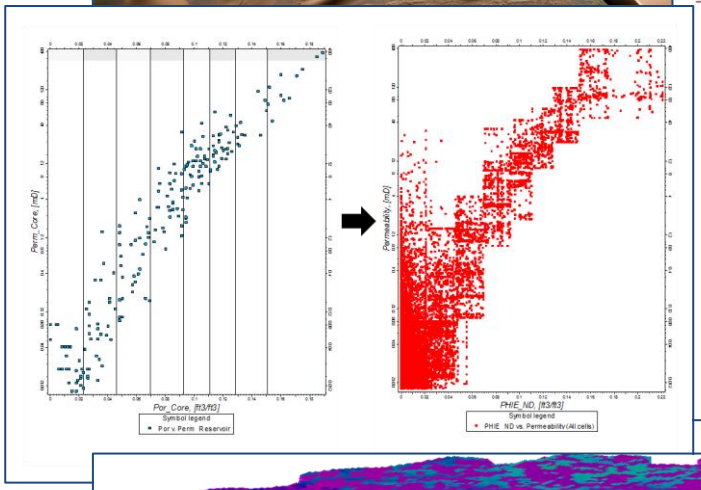


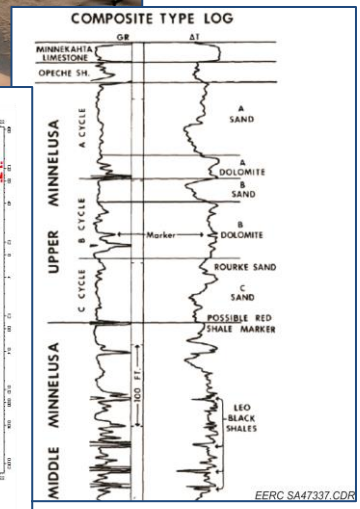

IEA Greenhouse Gas R&D Programme, 2009, Development of storage coefficients for $CO_2$ storage in deep saline formations: 2009/12, October 2009.

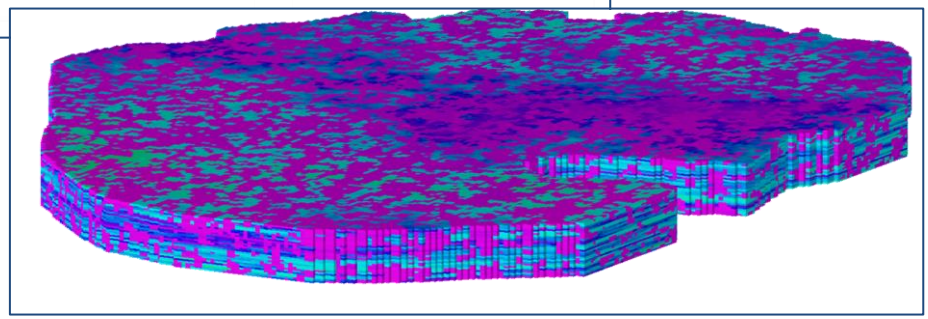
# Saline Formations: Modeling

## Approach

- Construct regional- to basin-scale geocellular models representing various depositional environments (primary and secondary).
- Use actual saline formations as a guide and data source.
- Supplement petrophysical properties using the Average Global Database (AGD).



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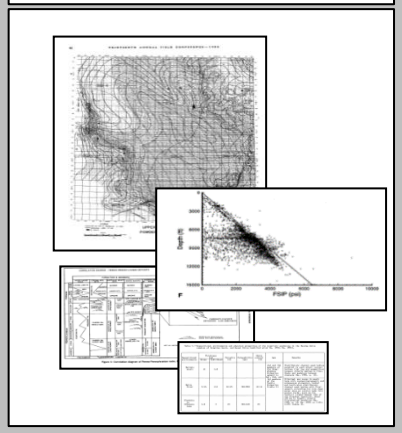
# Saline Formations Selected

| Saline Formations and Depositional Environments Selected | | |
|---|---|---|
| | Primary Depositional Environment | Secondary Depositional Environment |
| **Broom Creek** | Eolian | N/A |
| **Inyan Cara** | Delta | Fluvial |
| **Leduc** | Reef | Carbonate Shelf |
| **Minnelusa** | Eolian | N/A |
| **Mission Canyon** | Carbonate Shelf | Peritidal |
| **Qingshankou and Yaojia** | Lacustrine | Fluvial |
| **Stuttgart** | Fluvial | Delta |
| **Utsira** | Clastic Slope | Strand Plain |
| **Winnipegosis** | Reef | Carbonate Shelf |

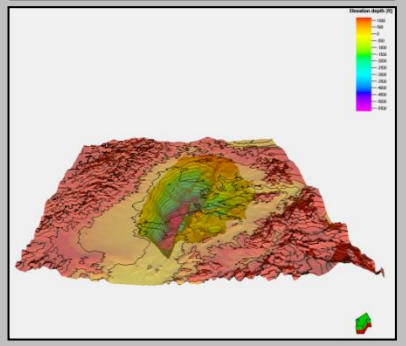
# Modeling Workflow

Literature Review

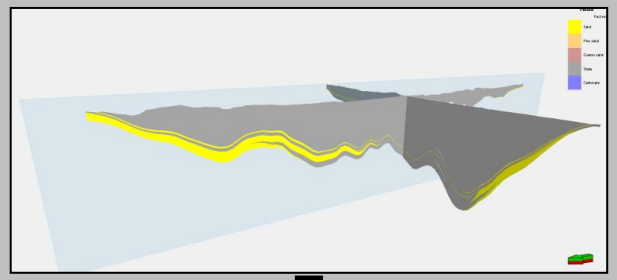


Digitize Data

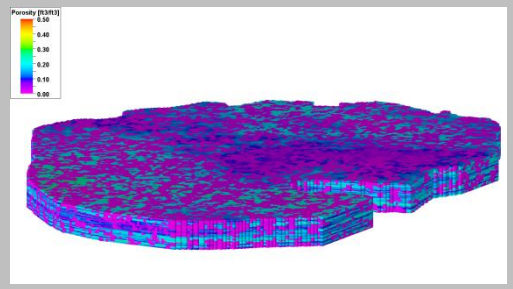
Structural Model



Facies Model

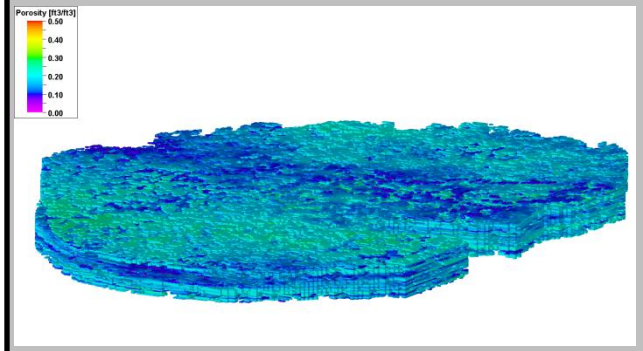


Petrophysical Modeling with AGD to Determine P10, P50, and P90 Cases

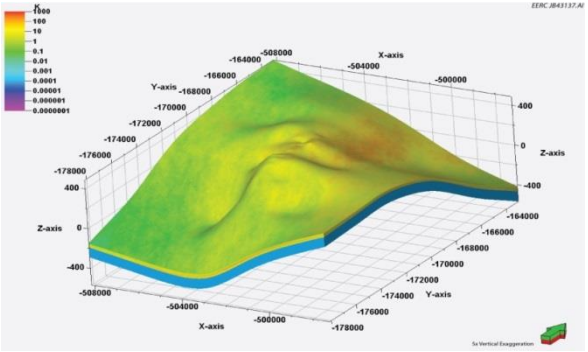


Clip Model to Effective Pore Volume, Based on Porosity and Permeability Cutoffs

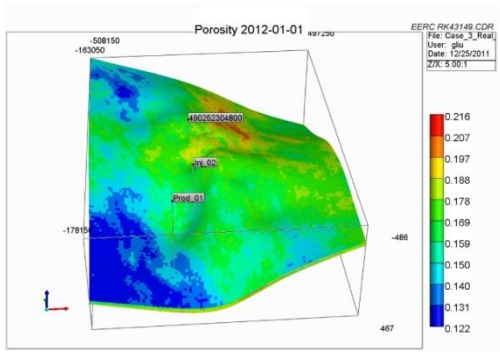
Static Geocellular Models



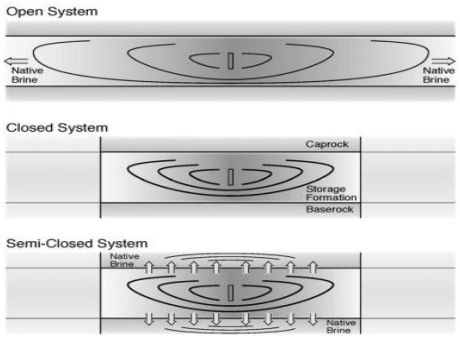
# Simulation Workflow



Geocellular Models with High-, Mid-, and Low-Pore Volume

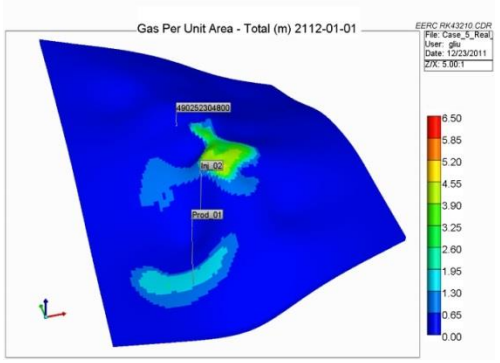



Injection Simulation Design

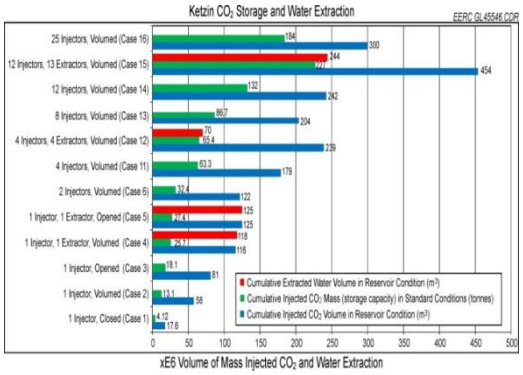



Boundary Condition Testing

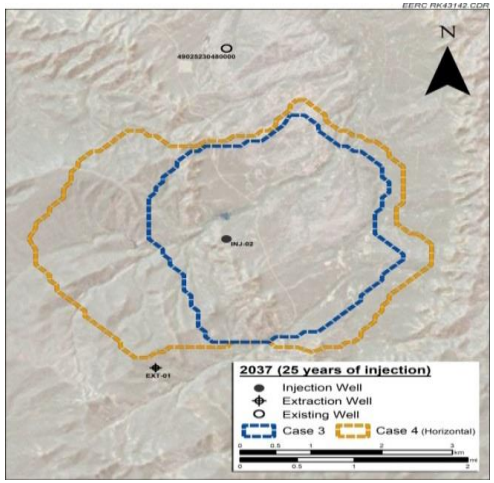
http://esd.lbl.gov/files/research/programs/gcs/projects/storage_resources/journal_3_NETL_zhou_etal_IJGGC.pdf




Operational Storage Capacity Enhancement



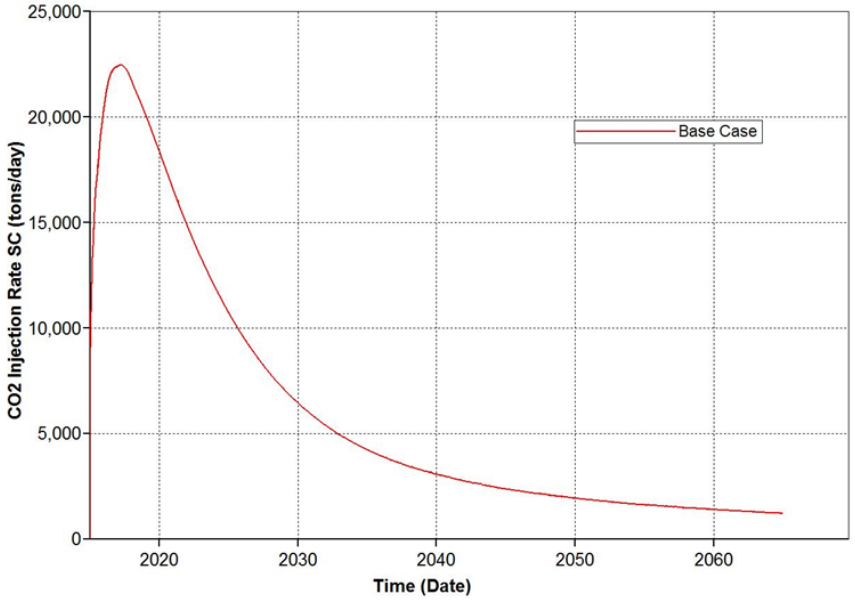

Dynamic Storage Capacity Estimates



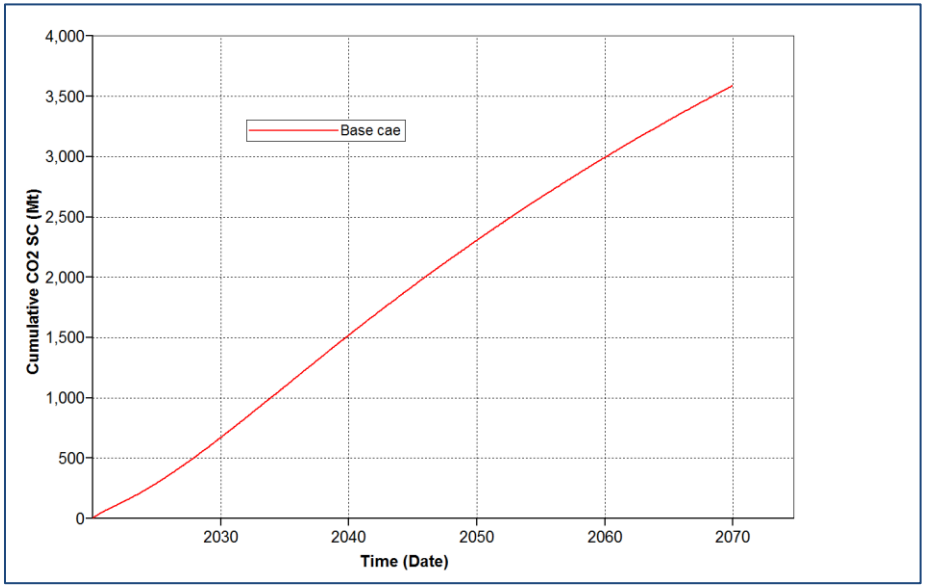

Storage Capacity Comparisons and Analysis

# Saline Formation Simulation

- Base case dynamic $CO_2$ injection simulations were performed.




CMG COMPUTER MODELLING GROUP LTD.

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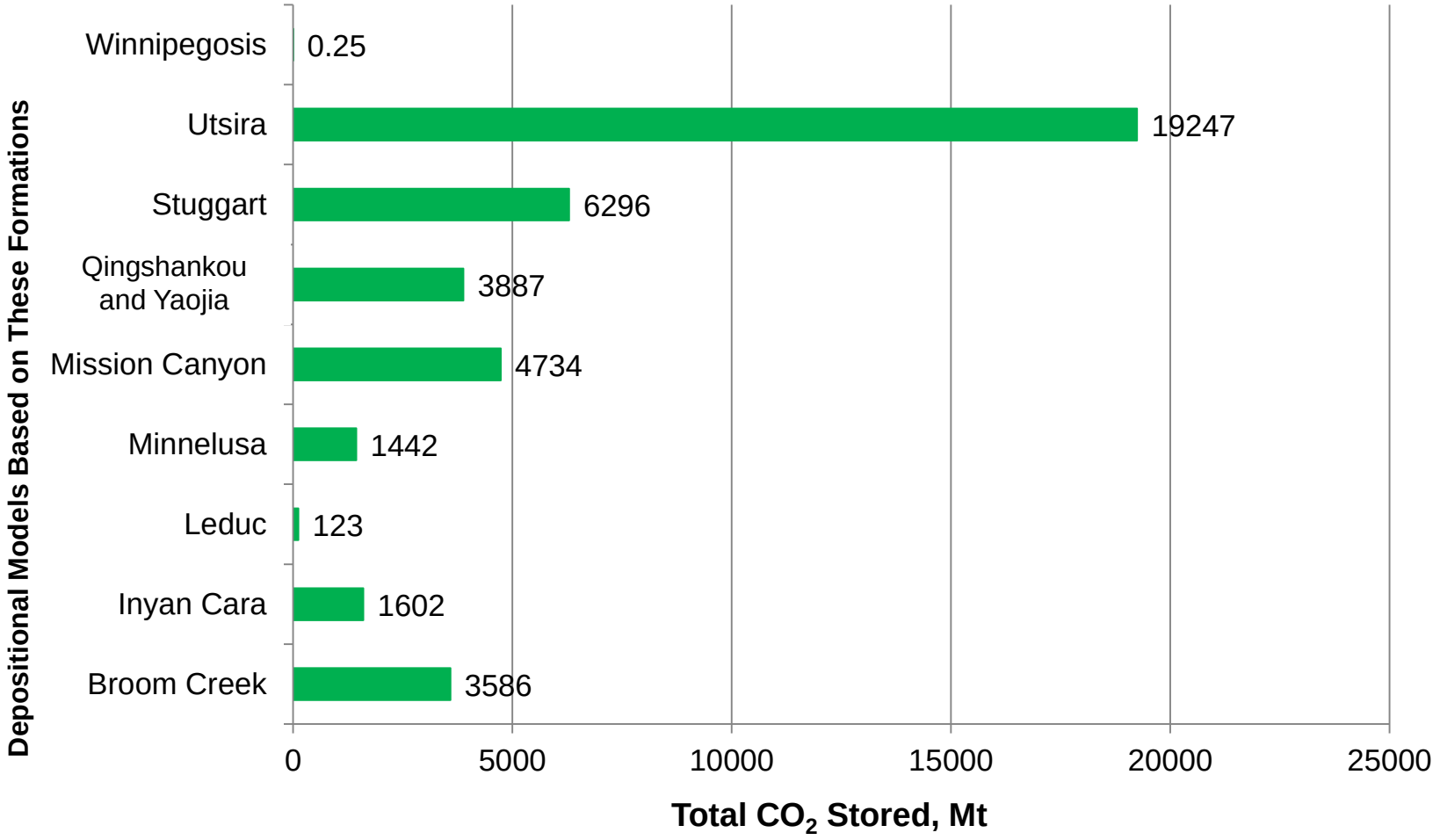
# Base Case Simulation Results

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# Base Case Simulation Results

| Formation | 1st Depositional Environment | 2st Depositional Environment | Injection Wells | Stored $CO_2$, Mt |
|---|---|---|---|---|
| Broom Creek | Eolian | | 138 | 3586 |
| Inyan Cara | Delta | Fluvial | 41 | 1602 |
| Leduc | Reef | Carbonate Shelf | 39 | 123 |
| Minnelusa | Eolian | | 663 | 1442 |
| Mission Canyon | Carbonate Shelf | Peritidal | 139 | 4734 |
| Qingshankou andYaojia | Lacustrine | Fluvial | 127 | 3887 |
| Stuggart | Fluvial | Delta | 122 | 6296 |
| Utsira | Clastic slope | Strand Plain | 391 | 19247 |
| Winnipegosis | Reef | Carbonate Shelf | 1 | 0.25 |

- Base Case simulations and stored volume are not meant to represent actual storage in these formations, the properties that were used in each depositional model were from the P50 properties from the AGD. The goal is to look at storage efficiency in different depositional environments.

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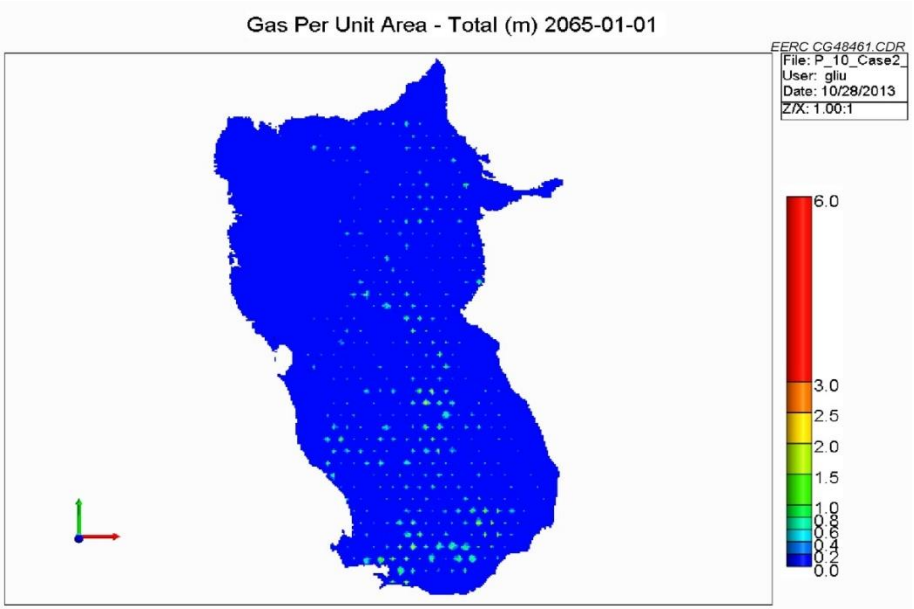
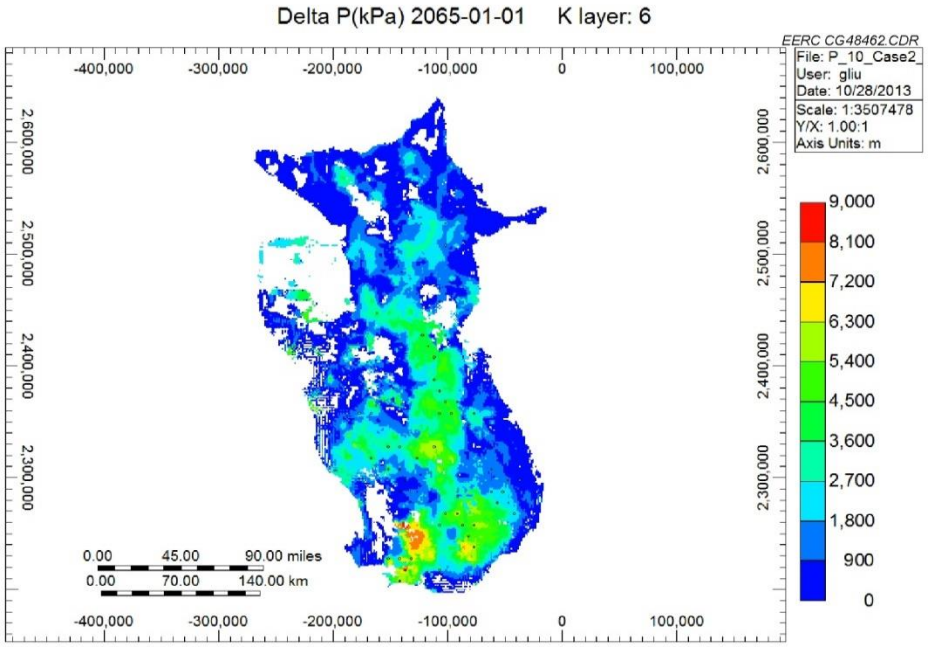
# Saline Formations: Next Steps

- Simulations will be conducted for P10, P50 and P90 realizations (base case was run on the P50 models, but may not result in the P50 storage efficiency).
- Optimization simulations will be performed. Multiple scenarios (e.g., water extraction, horizontal wells) will be designed to maximize storage resource and determine impact of site-specific factors and depositional environment on $CO_2$ storage resource.



# Hydrocarbon Reservoirs: Literature Review

- A literature review of current storage estimation methodologies in oil and gas reservoirs was performed.
- Data were collected from existing oil fields and ongoing $CO_2$ enhanced oil recovery (EOR) projects.
- A statistical analysis was performed for 31 $CO_2$ EOR sites.

# Hydrocarbon Reservoirs: Literature Review, continued

**Summary**

- The P10, P50, and P90 at 300% hydrocarbon pore volume injection (HCPVI) estimates for:
  - $CO_2$ retention = 23.1, 48.3, and 61.8% retention
  - Incremental oil recovery = 5.3, 12.1, and 21.5% original oil in place (OOIP)
  - Net $CO_2$ utilization = 4.5, 8.7, and 10.5 Mscf/stock tank barrel (STB)
- Additional investigation into the factors that control these parameters in the existing projects are being performed (depositional environments, operational plans, etc.). In this way, candidate oil fields not currently under $CO_2$ injection, can be screened and estimates of the associated $CO_2$ storage potential can be made.

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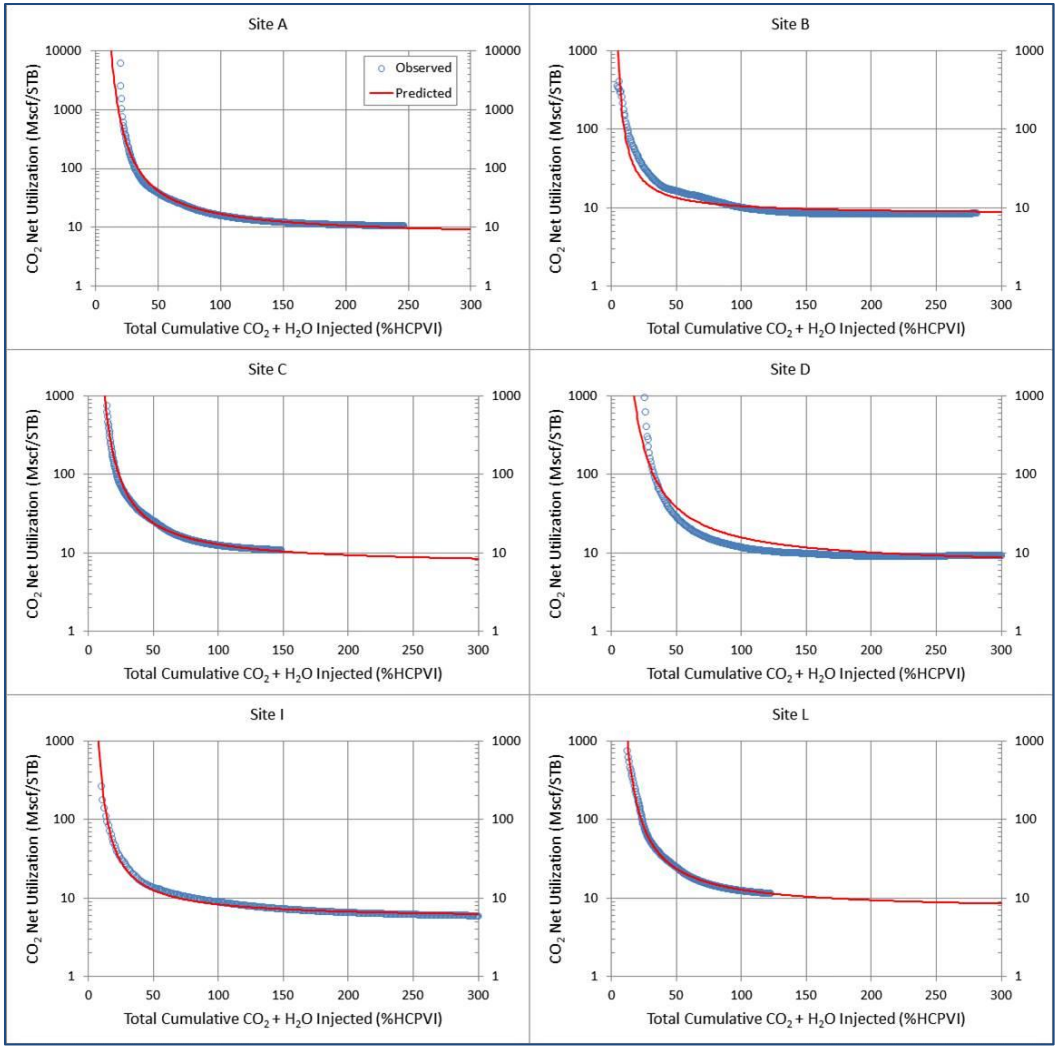
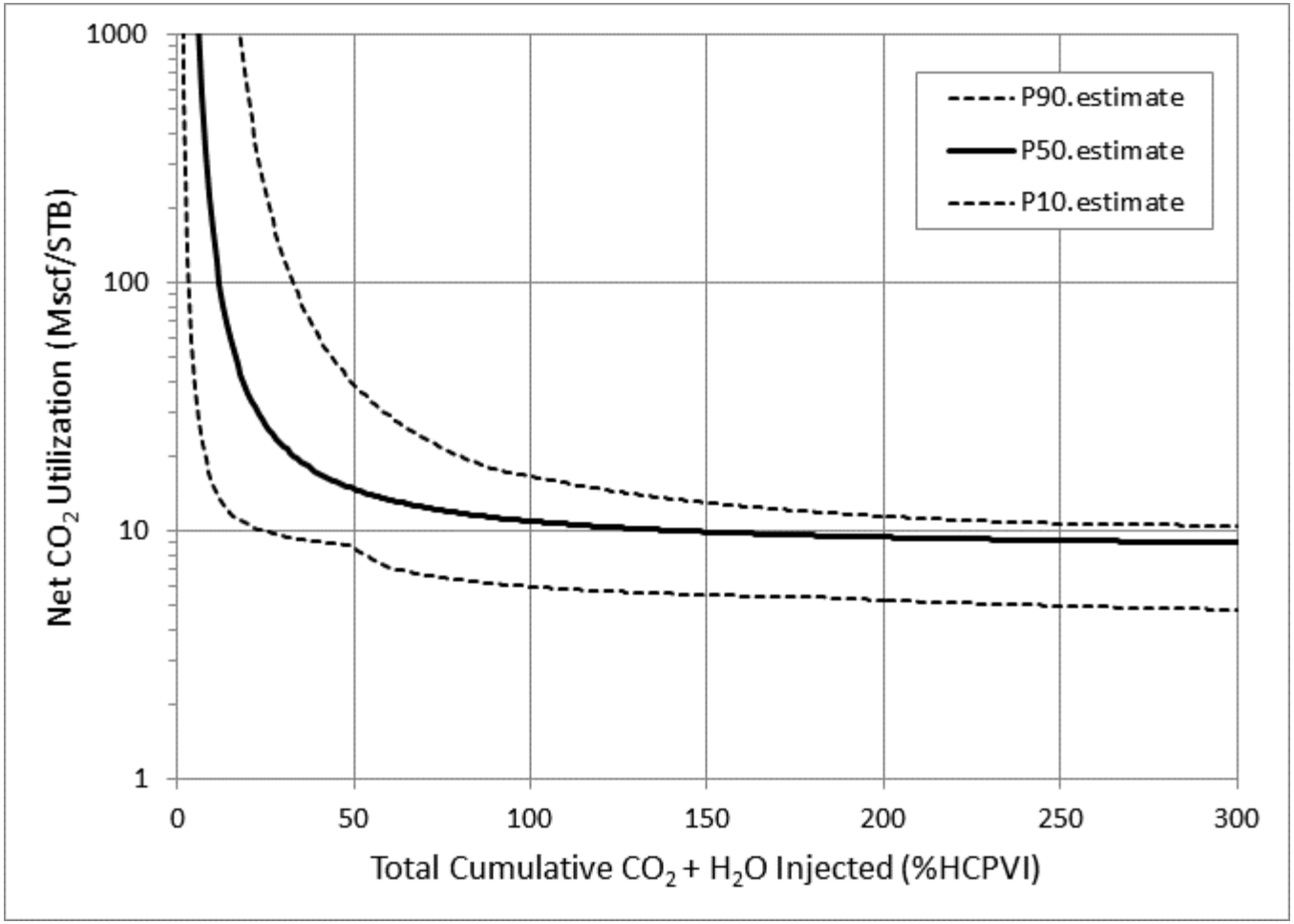
A paper with these findings is currently under review by the Society of Petroleum Engineers for publication in its journal *Reservoir Evaluation & Engineering – Reservoir Engineering.*

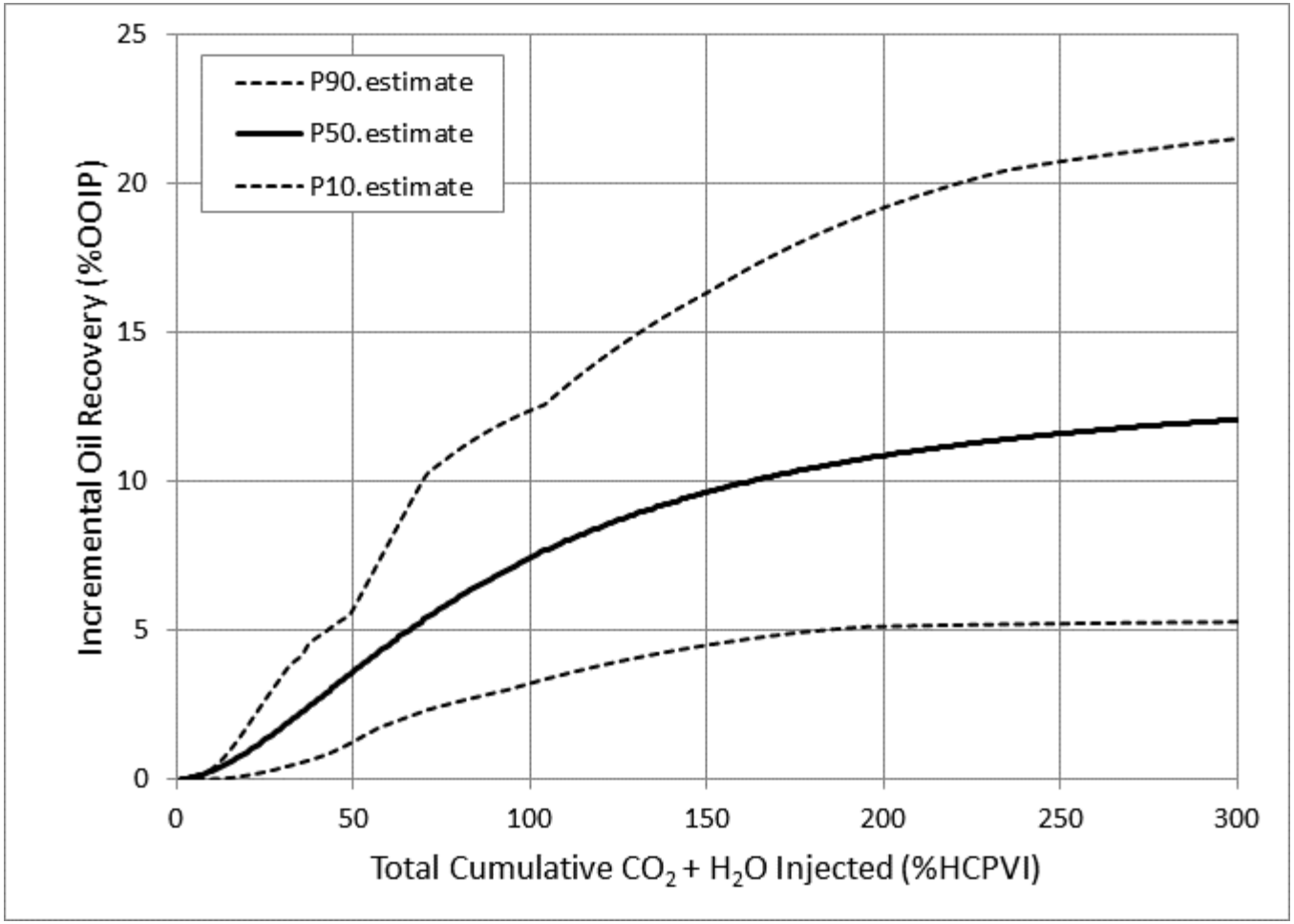
# Net $CO_2$ Utilization Response



# Uncertainty Quantification: Net $CO_2$ Utilization P10, P50, and P90



# Uncertainty Quantification: Incremental Oil RF P10, P50 and P90



# Hydrocarbon Reservoirs: Modeling

## Approach

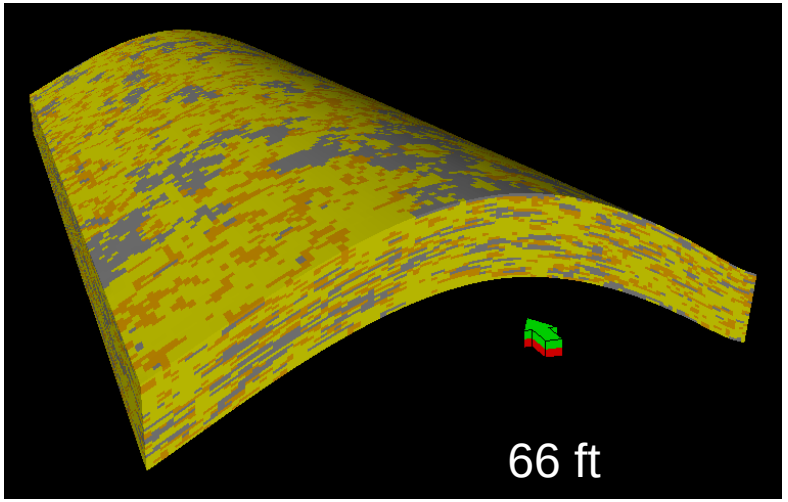
- Construct 12 field-scale models (2 miles x 4 miles) representative of existing oil fields.
- Statistics for P10, P50, and P90 values derived from actual EOR oil fields.
- Porosity and permeability properties populated into each model by the AGD.

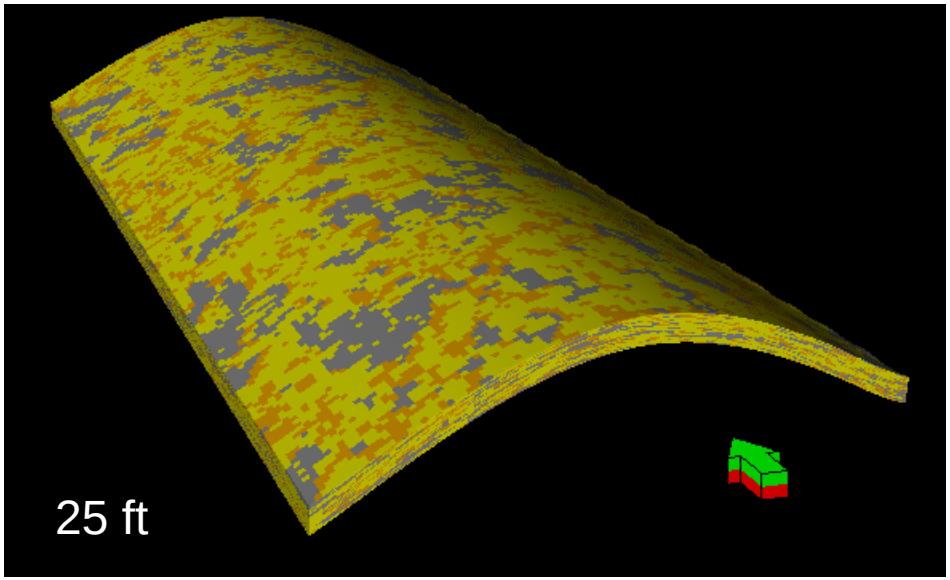
Hydrocarbon reservoir model characteristics

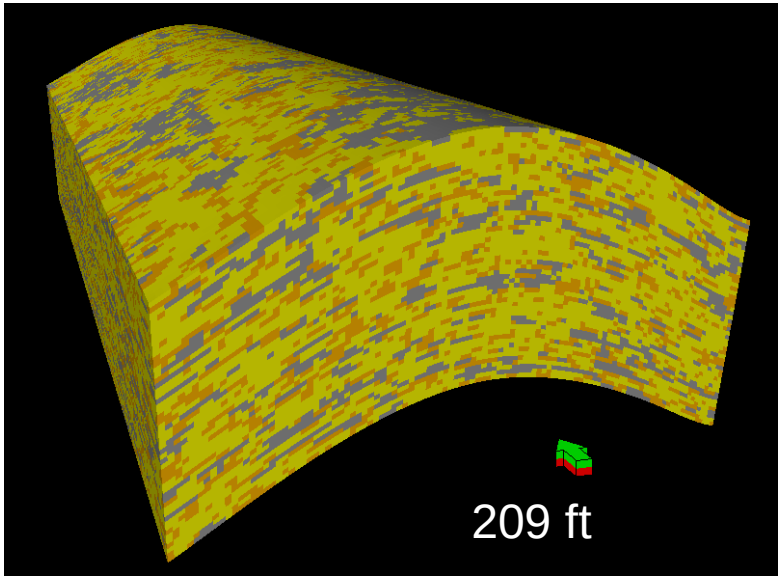
| Structure | Lithology | Thickness | Depth | Ave. Reservoir Porosity |
|---|---|---|---|---|
| Anticline | Fluvial | 25 | 4000 | 26.6 |
| Anticline | Fluvial | 25 | 8000 | 26.6 |
| Anticline | Fluvial | 66 | 4000 | 26.6 |
| Anticline | Fluvial | 66 | 8000 | 26.6 |
| Anticline | Fluvial | 209 | 4000 | 16.9 |
| Anticline | Fluvial | 209 | 8000 | 16.9 |
| Anticline | Carbonate shallow shelf | 25 | 4000 | 33.7 |
| Anticline | Carbonate shallow shelf | 25 | 8000 | 33.7 |
| Anticline | Carbonate shallow shelf | 66 | 4000 | 34.5 |
| Anticline | Carbonate shallow shelf | 66 | 8000 | 34.5 |
| Anticline | Carbonate shallow shelf | 209 | 4000 | 21.9 |
| Anticline | Carbonate shallow shelf | 209 | 8000 | 21.9 |

# Hydrocarbon Reservoirs: Structural Modeling

- Anticline structures with 100-ft closure were used with reservoir thicknesses of 25, 66, and 209 ft thick, based on statistics of operating $CO_2$ EOR projects.

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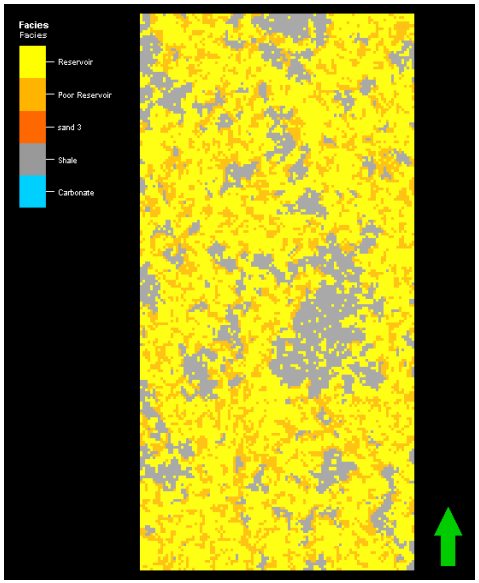
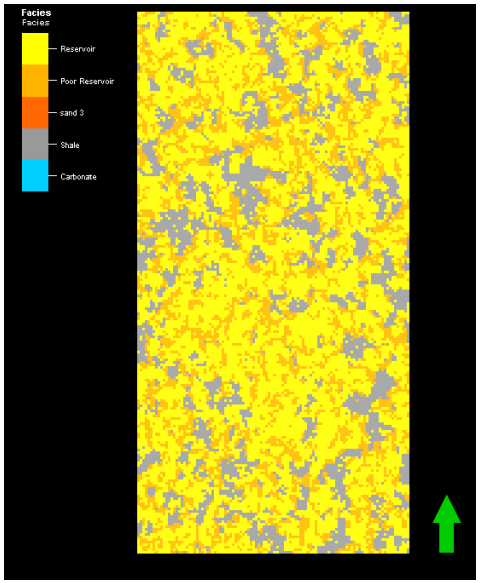
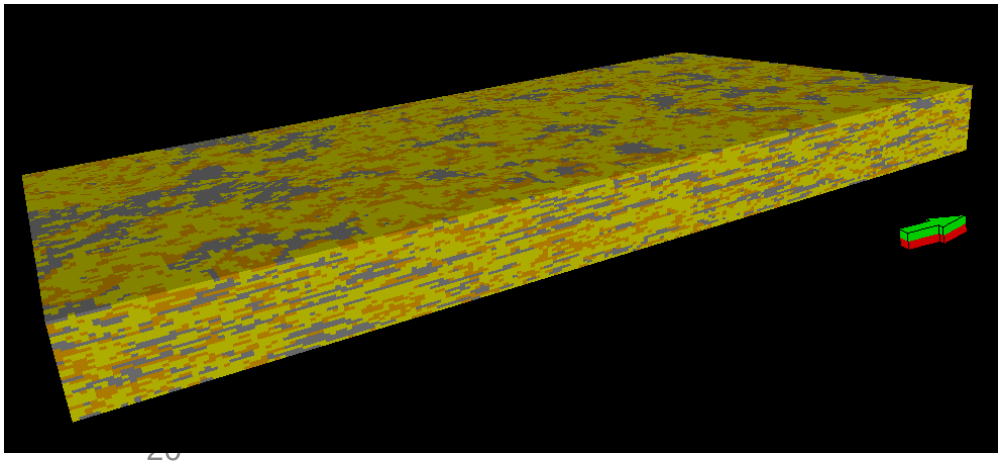
# Hydrocarbon Reservoirs: Fluvial Facies

- Fluvial facies were populated using a combined object-modeling/multiple-point statistical algorithm.
- Training image was based on sections of the Platte River in Nebraska and logs from the Weber Sandstone, Rangely Field, Colorado.
- Three facies were populated: reservoir, poor reservoir, and shale.

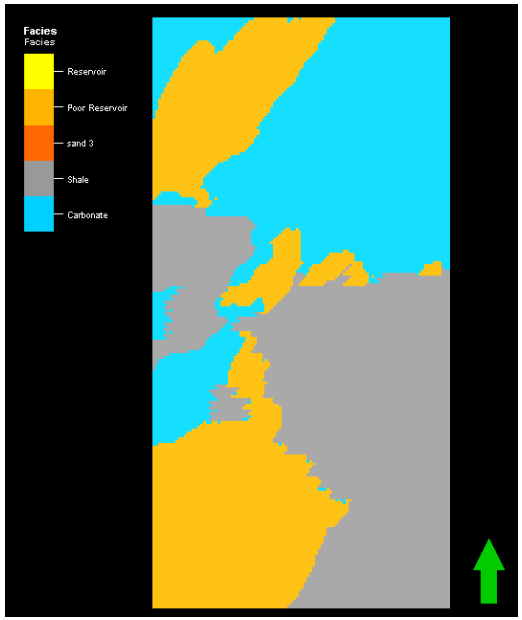


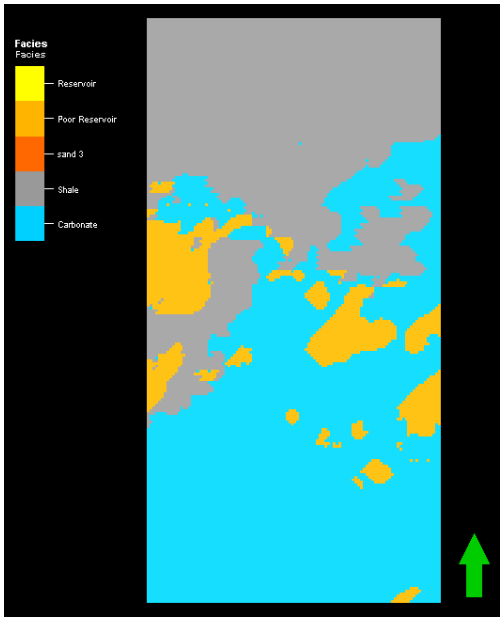



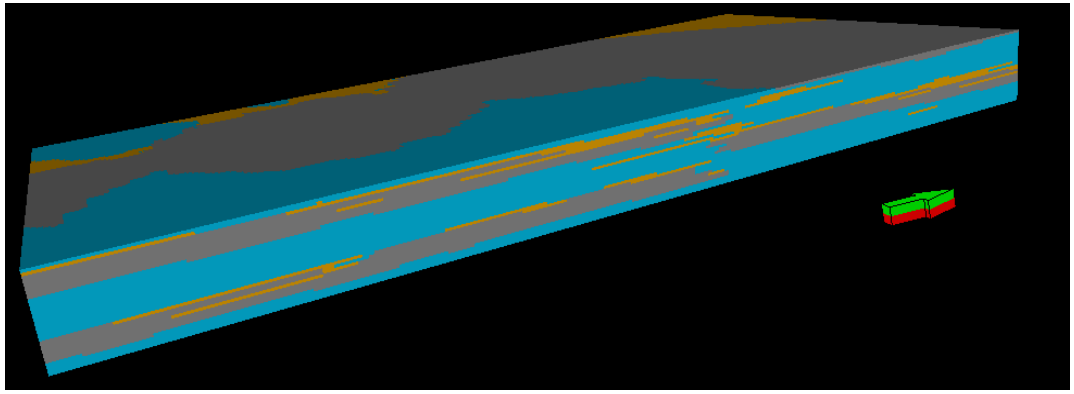



# Hydrocarbon Reservoirs: Carbonate Facies

- Carbonate facies were populated using a multiple-point statistical algorithm.
- Training image based on carbonate shelf block model and log from Central Vacuum Unit, New Mexico.
- Three facies were populated: reservoir, poor reservoir, and shale.

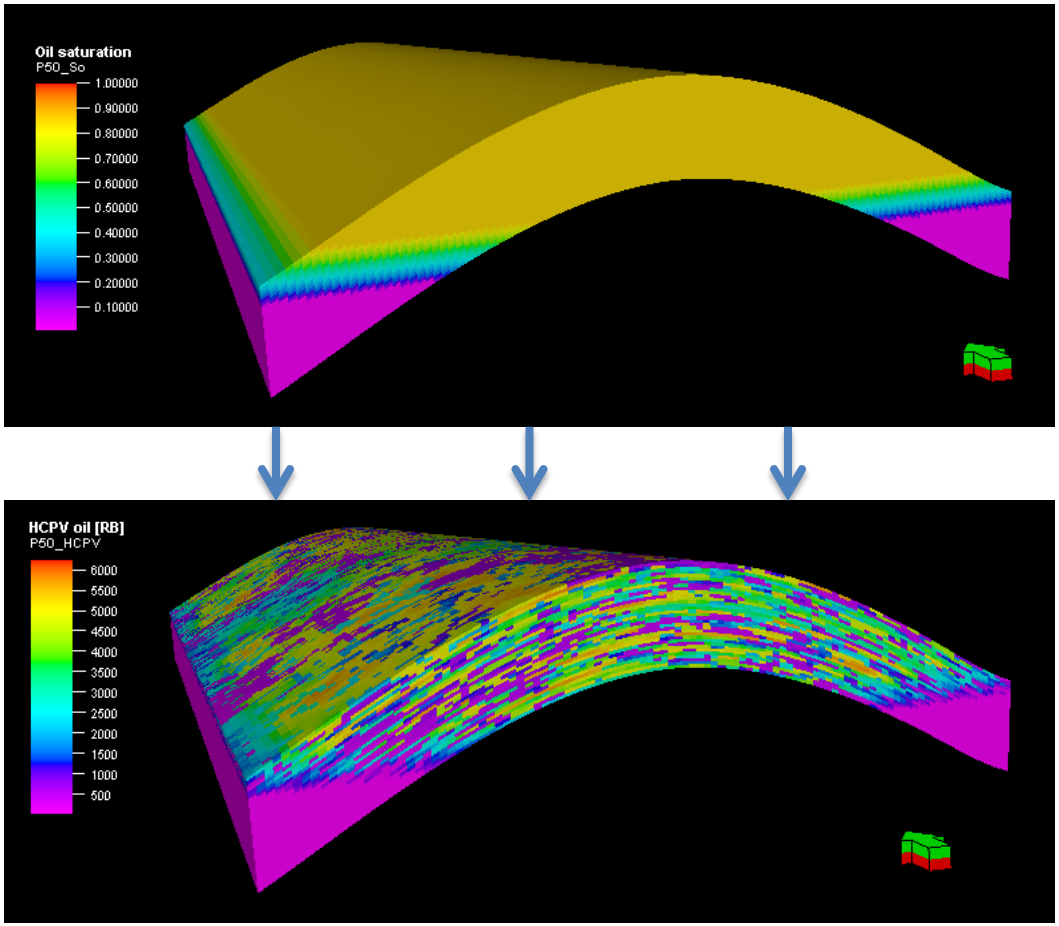


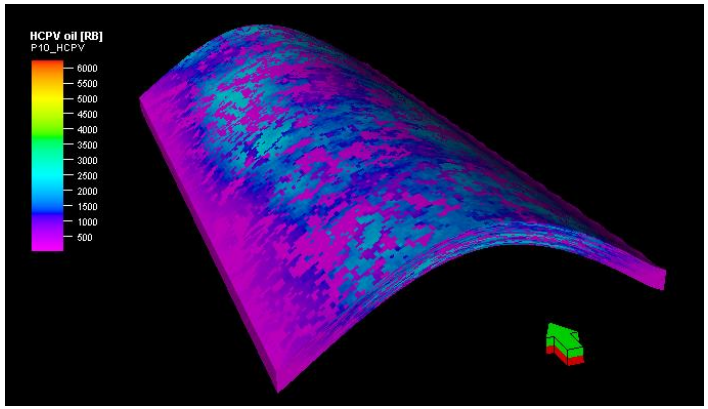



# Hydrocarbon Reservoirs: Model Saturations

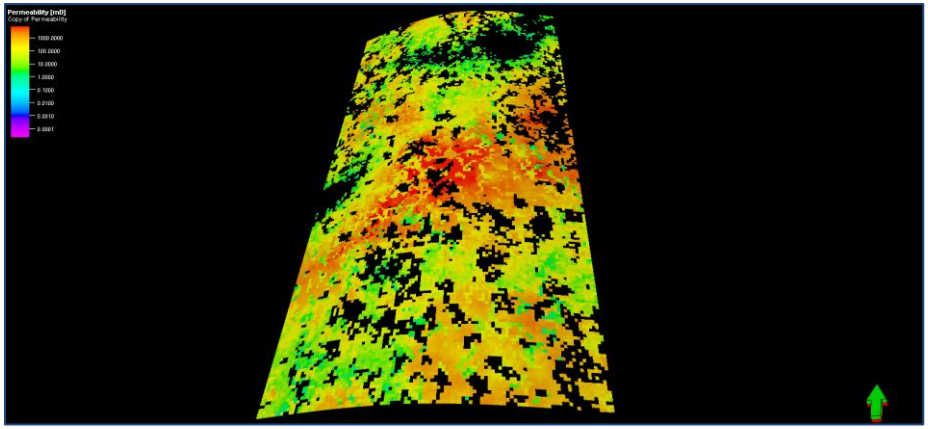
- Oil saturations were incorporated to match statistics of OOIP from the $CO_2$ EOR database.
- Oil–water contact, maximum saturation and residual oil zones were adjusted to fit the target value.

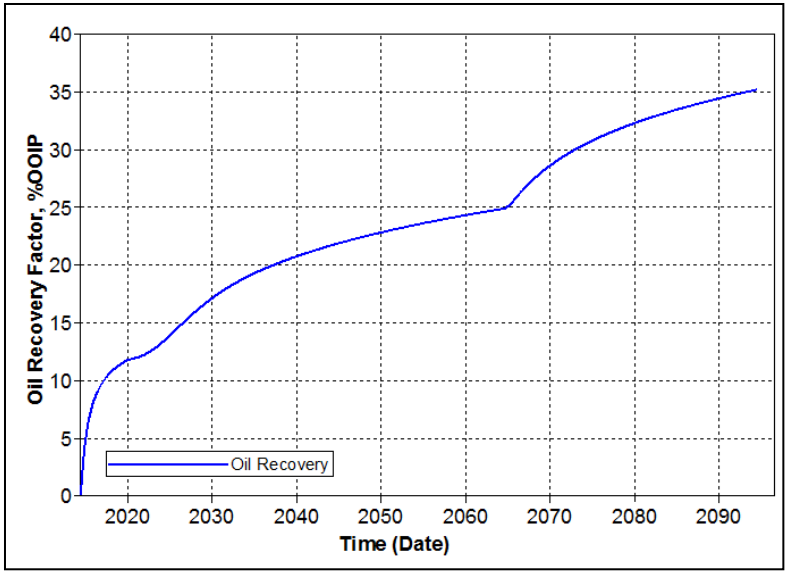


# Hydrocarbon Reservoirs: Simulation

- Perform dynamic simulations, including primary, secondary, and tertiary recovery ($CO_2$), to evaluate the relationship between $CO_2$ storage and EOR.
- Utilization and recovery factors will be assessed.
- Assess the balance between associated $CO_2$ storage and $CO_2$ EOR.



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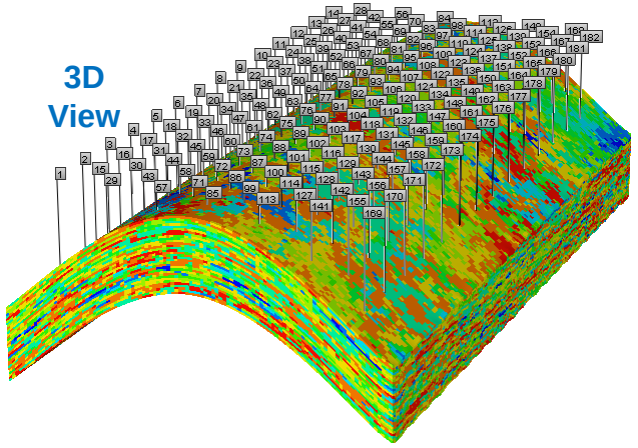
# Hydrocarbon Reservoirs: $CO_2$ Enhanced Gas Recovery (EGR) and Storage

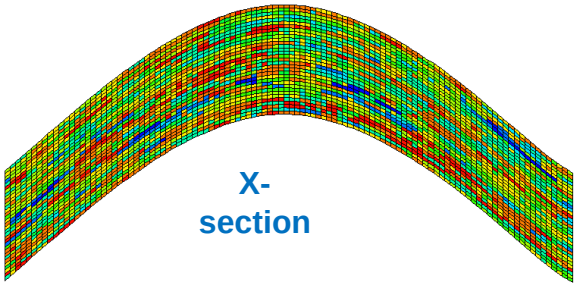
- **Why gas reservoirs?**
  - EGR potential exists in depleted conventional gas reservoirs.
  - Demonstrated ability to trap and store hydrocarbons for millions of years.
  - Typically well characterized because of historic hydrocarbon production.
  - Large storage resource potential after ultimate recovery of approximately 65%–75% of original gas in place (OGIP).
- **Objectives**
  - Evaluate reservoir response to the injection and long-term storage of $CO_2$ in gas reservoirs.
  - Determine $CO_2$ recovery efficiency.
  - Correlate gas recovery and $CO_2$ storage efficiency.
  - Assess engineering constraints for $CO_2$ injection and storage in a natural gas reservoir.

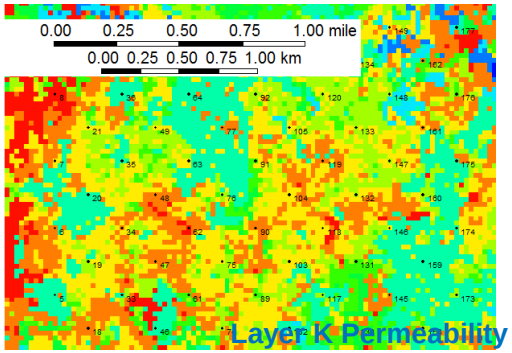
# Hydrocarbon Reservoirs: $CO_2$ EGR and Storage, continued

## Approach

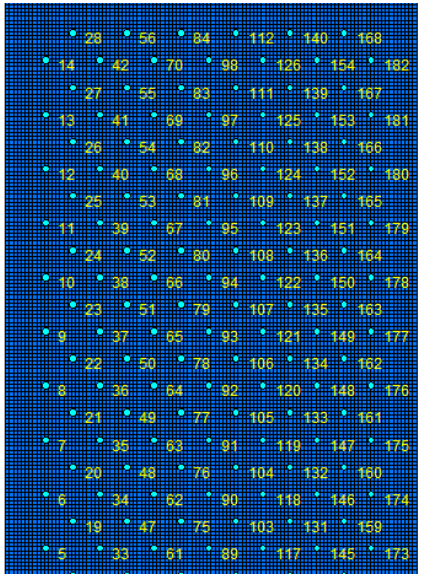
- Analysis of existing injections
- Field scale modeling and simulation
- Focus on majority (gas condensate)
- Various depositional environments
- Secondary or tertiary
- Efficiency and timing of $CO_2$ injection
- Potential of $CO_2$ storage and utilization




Well Pattern



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# Summary

**Task 2**

- Nine base case models have been constructed.
- Base case simulations finished.
- Optimization cases started.

**Task 3**

- Twelve base case models have been constructed.
- One base case oil reservoir simulation finished.
- Base case gas reservoir simulation started.
- Optimization cases for both oil and gas reservoirs will be conducted.

**Future goals – validate or adjust methods and storage efficiency values for saline formations and hydrocarbon reservoirs. Consider depositional environments and operational approaches.**

# Contact Information

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# Disclaimer